Bumble bee colony decline in greenhouses with supplemental lighting

Tjeerd Blacquière, Bram Cornelissen & Jeroen Donders
Applied Plant Research (PPO), Bee Unit, PO Box 69, 6700 AB Wageningen, The Netherlands, E-mail: tjeerd.blacquiere@wur.nl

Supplemental lighting with high light levels becomes more widely applied in greenhouses with tomato and some other vegetable crops. Pollinating insects, bees and bumble bees, have to cope with the increased complexity of the environment. From agricultural practice many problems were reported.
Bumble bee colonies with marked workers in four age cohorts were placed in lit and unlit tomato and bell pepper greenhouses. The fate of the age cohorts and the development of the colonies were followed for a month. Immediately after placement in the greenhouses the colonies lost 50-90% of their workers. After that the colonies started to recover by the hatching of new workers. However, in lighted greenhouses the colonies hardly grew or even continuously declined. Development in pepper greenhouses was better than in tomato greenhouses.

Keywords: bumblebee, *Bombus terrestris,* tomato, sweet pepper, supplemental lighting, worker loss, worker age

Greenhouse tomatoes and a few other crops are pollinated by workers and males from commercially reared bumble bee colonies. In recent years tomato and sweet pepper growers in the Netherlands, Scandinavia and Canada started to light their crops with high intensity discharge lamps, mainly high pressure sodium lamps. High levels of light are used, 6,000 through 10,000 lux, this is about 70-120 μmol $m^{-2}s^{-1}$ PPF (photosynthetic photon flux). By extending the day length beyond natural in December more than 80% of the daily light integral can be supplied by the lamps, on very dark overcast days even more than 95%.

It was found in practice that more bumble bee colonies were needed when tomato crops were lighted, especially during the darkest periods of the year (December, January). Colonies appeared to decline very quickly, especially when introduced in periods with heavy overcast conditions. It seemed that the radius of action of the colonies decreased from the normal 100 m to about 30 m. Often dead workers with pollen loads in their corbiculae were found in the greenhouse: these workers obviously had successfully foraged, but not found their way home. One of the reasons might be that the workers experience difficulties with their orientation, and therefore had run out of fuel before finding the nest.

In this research we compared the performance of colonies immediately after introduction in a lighted tomato and a lighted sweet pepper greenhouse. In a second experiment unlit tomato and sweet pepper greenhouse compartments were used as controls. Tomato flowers only provide pollen; sweet pepper flowers provide pollen and nectar.

MATERIAL AND METHODS

Experiment 1

The study started on January 3, 2006 with ten colonies in the rearing facility. The colonies were produced by Syngenta Bioline Bees, and then contained 10-15 workers each. These workers were marked two colour dots on their thorax with 'uniPosca' markers: one to represent the colony, and one to represent the age cohort. New cohorts were marked after one, two and three weeks. At that moment the colonies contained about 75 workers in four age cohorts. They were placed in the greenhouses on January 26. Five colonies were placed in a commercial sweet pepper greenhouse at regular distances (20 m) along the main path. These five colonies were the only bumble bee colonies in the greenhouse. They were placed on the greenhouse floor, against a foundation pillar. Five other colonies were placed along the middle path in a commercial tomato greenhouse, at regular distances and between the already available bumble bee colonies. The colonies were placed on the rock wool slaps, about 50 cm above the soil. After introduction the boxes were opened and the behaviour of the workers that left the colonies was observed. Then the colonies were left undisturbed. Observations were made on January 30 and on February 6, 13 and 20.

Experiment 2

In a second experiment non lit sweet pepper and tomato greenhouses were added. The 20 bumble bee colonies were purchased from Syngenta Bioline Bees, and placed in the rearing unit of PPO Bee Unit on February 6, 2006. The first cohort was marked on February 7-9, the second cohort on Febrary 20-22, 2006. On February 22 the colonies were placed in the greenhouses, five colonies per greenhouse. The colonies contained 75-80 workers in two age cohorts. The experiment ran through 20 March.

Observations

On January 30 one quarter of an hour every colony was observed regarding the flight activity (workers flying in and out). However, since the activity was too low to get enough observations, this was refrained from further on. On all observation dates early during the day the exit opening of the nest boxes was closed, and at least two hours the workers had the opportunity to return home and enter the colonies. After that the colonies were removed and observed in a closed room with only red light. The number of workers per age cohort in each colony was registered. The population in each colony was made up of four marked age cohorts (two in the second experiment), one cohort of unmarked newly hatched workers, and a mixed age cohort of foreign workers (those that had a different colony code). After the observations the colonies were returned the next day to the greenhouses, and placed on exactly the same spot where they had been before. In the greenhouse dead workers were collected, and their colour codes and the place of finding were registered.

RESULTS

Experiment 1

When introduced the colonies consisted of 12 workers in the first, 12 in the second, 20 in the third and 30 in the fourth age cohort. This was similar in the pepper and tomato greenhouses (Figs. 1 and 2, first observation dates). The colonies

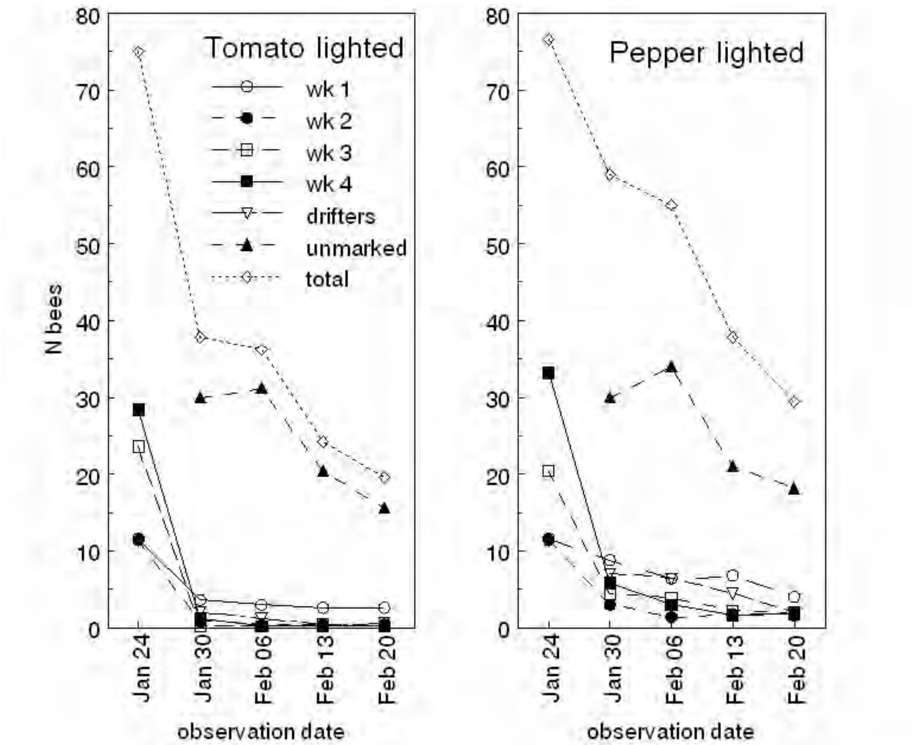

Figure 1 (left) *and 2* (right). Mean numbers of workers present in colonies of *Bombus terrestris* in a tomato (1) and a sweet pepper (2) greenhouse. Four age cohorts were marked (wk 1-wk 4). On January 30 a cohort 'drifters' and on February 6 a cohort unmarked was added. Unmarked was not counted on January 30, but estimated to be 30 individuals. The colonies were introduced in the greenhouses on January 26, 2006.

lost most of their workers very quickly: from 76 to 8 in the tomato greenhouse and from 76 to 29 in the pepper greenhouse from 26 through 30 January (Figs. 1 and 2, second observations). The number of (unmarked) newly hatched workers was not counted on 30 January, but estimated to be about 30 workers (without losses). Part of the workers drifted to other colonies: seven drifters per colony were found in the pepper greenhouse, two per colony in the tomato greenhouse. Most of the drifters originated from nearby colonies.

From 6 February onward the newly hatched workers became the most important group. This group seems to be less susceptible to losses, although there is of

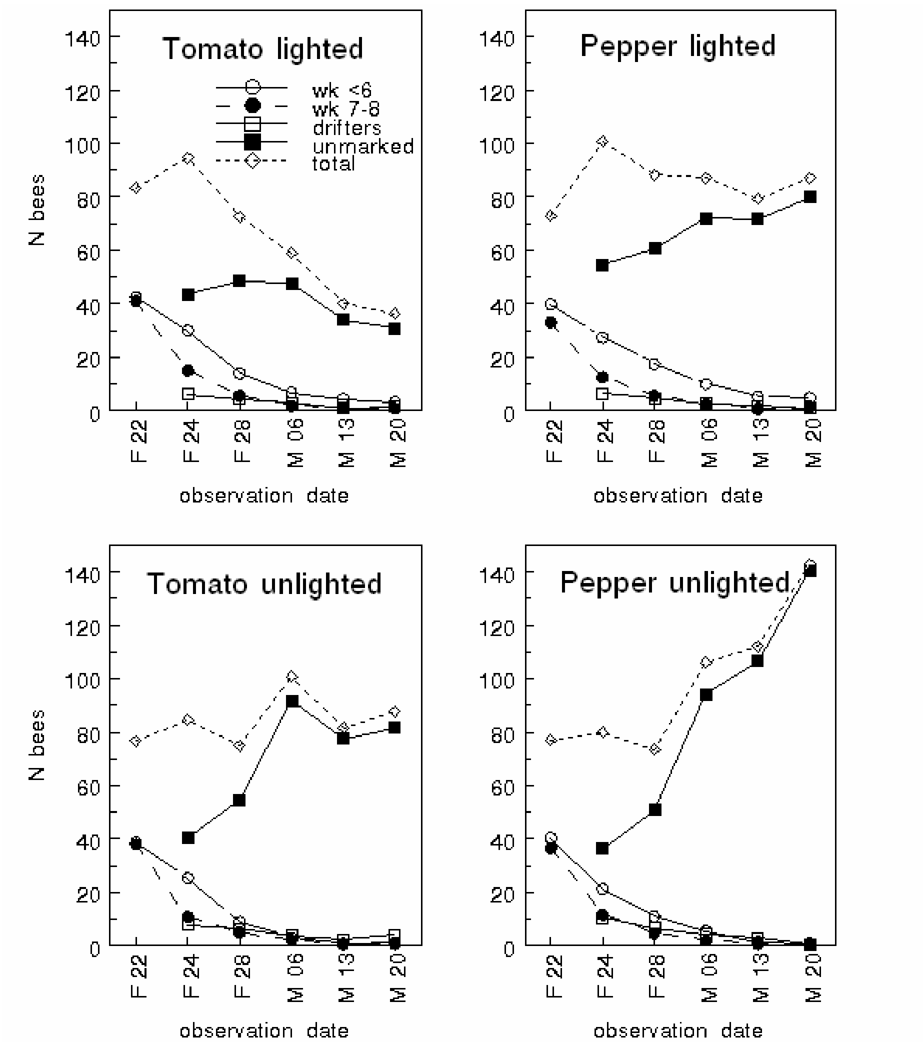

Figure 3 (left) *and 4* (right). Mean numbers of workers present in colonies of *Bombus terrestris* in a sweet pepper (3) and a tomato (4) greenhouse. Top graphs: lighted, bottom graphs: not lighted. Two age cohorts were marked (wk <6: all workers hatched until the end of week 6; wk 7+8: all workers hatched in week 7 and 8). F: February, M: March.

course also continuous growth that compensates for losses. Three of the original four age cohorts lost their workers with the same rate, only the oldest cohort was less prone to lose workers. Of the 325 workers lost in the tomato greenhouse 10 were recovered on January 30, of the 225 lost in the pepper greenhouse 18. Most of them were found close to the main path (= close to the nest boxes).

The losses were higher in the tomato greenhouse than in the sweet pepper greenhouse. The colonies in the pepper greenhouse continued development, and started to produce males and queens. The colonies in the tomato greenhouse were drawn back in development and only produced workers. In the colonies in the pepper greenhouse at the end of the experiment males had hatched (5.4 per colony) and a few young queens (1 per colony).

Experiment 2

When introduced in the greenhouses the colonies consisted of 40 workers in the first and 38.5 workers in the second cohort. This was similar in the tomato and pepper greenhouses, and in the lit and unlit greenhouses (Figs. 3 and 4, first observation date, Feb 22). Again the initial population of workers rapidly decreased, in both tomato and sweet pepper greenhouses, irrespective the lighting (Figs. 3 and 4, second observation date, Feb 24). After two days in the greenhouse the original population was about halved. Part of the workers drifted to other colonies: 6-11 workers per colony originated from another colony (wrong code). In this experiment the number of drifters was equal in tomato and pepper greenhouses. Most of the drifters originated from nearby colonies. In all treatments the majority of the drifters were from the youngest age cohort (cohort 7-8).

The colonies developed better without supplementary lighting, and better in the pepper greenhouses than in the tomato greenhouses. At the end of the experiment the colonies in the lighted tomato greenhouse only consisted of 36 individuals, in the not lighted greenhouse 88. In the pepper greenhouses respectively 87 in the lighted and 143 in the not lighted treatment were present.

The development of the colonies was also affected: in the lighted tomato greenhouse at termination of the experiment only very few male individuals had hatched (3 per colony), in the unlighted greenhouse 12. In pepper this amounted 12 and 61 in lighted and unlighted greenhouses, respectively.

DISCUSSION

Worker losses upon introduction in the greenhouse

In both experiments the population of workers declined very quickly upon introduction in the greenhouse. In both cases the weather was rather dark during introduction, a condition that from agricultural practice already was suspected to cause initial losses (Hüvermann & Moerman 2005, Moerman 2005). After four days (Exp. 1) and six days (Exp. 2) less than a quarter of the workers were still present. In the first experiment the cohort of newly hatched workers could hardly compensate for these losses. The colonies continued to decline although with a lesser speed than the first days. In the second experiment the cohort of newly hatched workers did compensate for the losses, except in the lighted tomato greenhouse. We can only speculate about what caused the difference between the two experiments but it is probable that the increased light input from the sun is an important factor: from end of January to the end of February the daily light integral almost doubles and the photoperiod is expanded by almost two hours.

In the first experiment the losses from the original four cohorts were greater in the tomato greenhouse than in the pepper greenhouse, but the number of drifters present in the colonies was lower. This might be explained by the presence of many more colonies in the tomato greenhouse: the grower already had placed many colonies to ascertain pollination of all flowers. Part of the lost workers may have drifted to these colonies (which we did not check).

A striking observation was that the oldest cohort of workers was the least prone to loss (both experiments). When speculating that high initial losses of workers from commercially reared colonies upon introduction might be caused by lack of experience and training of the dark grown novices this seems contradictory. However, this may be explained by the caste differentiation in bumble bees that is quite different from that in honey bees. In bumble bees foraging is confined to the strongest and heaviest workers, whilst the smaller workers do the jobs inside the nest (Free & Butler 1959). The first hatched workers in a colony are generally smaller than the later generations. So the oldest cohorts were allowed to stay in the nest and therefore did not get lost in the greenhouse.

Further development of the colonies

The new unmarked cohort had to take over most of the duties in the colonies very quickly. This only marginally succeeded in the first experiment (only with pepper some later development stage of the colony, hatching of males was reached), but did work in experiment 2. However there were big differences between tomato and pepper, since in the latter crop colonies remained stable (lighted) or even grew (unlighted), whilst in tomato the colonies at best remained stable (unlighted). This was also reflected in the numbers of males per colony. Initial loss of workers and drifting of workers appeared to be independent of the crop and lighting. In research of Birmingham and Winston (2004) environmental stimuli (coloured marks placed in the greenhouse) also exhibited a different effect on initial drifting compared to performance of trained foragers.

What explains the better performance in pepper greenhouses? Pepper flowers provide both nectar and pollen, tomato flowers only pollen. Combined foraging for nectar and pollen proved to enhance pollen collection in research of Weinberg & Plowright (2006). If so addition of (artificial) nectaries/flowers in tomato greenhouses might increase pollination effectiveness. One may speculate that the availability of nectar in pepper flowers is most important, but the absence of competition between colonies may also have been a reason (only 5 colonies in the pepper greenhouse, and at least 20 competing colonies in the tomato greenhouse).

Are big losses from commercial colonies upon placement a general phenomenon, independent of the greenhouse environment and lighting? More research is needed to sort this out, but in an extensive survey in many apple orchards in May 2006, in two to three weeks bumble bee colonies grew from 70 to 500 individuals, workers and males (Van der Steen, in prep.).

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